BRL

REPORT NO. 1196
MARCH 1963

A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES

Heinz G. Poetzschke
Donald F. Menne

RDT & E Project No. 1M222901A215

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1196

MARCH 1963

A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES

Heinz G. Poetzschke
Donald F. Menne

Ballistic Measurements Laboratory

Partially supported by the Harry Diamond Laboratories

RDT & E Project No. 1M222901A215

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1196

HGPoetzschke/DFMenne/jdk
Aberdeen Proving Ground, Md.
March 1963

A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES

ABSTRACT

A stereophotogrammetric method has been developed for the determination of the topography of liquid surfaces, which serve as an analogue for gas pressures and velocities in the evaluation of turbine performance.

An instrumentation system has been constructed, consisting of two modified Wild RC-7 cameras with microflash projection of a random pattern of spots to identify the water table surface.

The reduction of the data was accomplished by both analogue and analytical methods. The analogue method, including automatic plotting, was the more economical and yielded an accuracy of ± 120 microns. The analytical method, involving manual plotting, resulted in an overall accuracy of ± 60 microns, and an accuracy of ± 30 microns for small areas near the center.

TABLE OF CONTENTS

	Page
ABSTRACT	3
INTRODUCTION	7
MEASUREMENT METHOD	7
PHOTOGRAMMETRIC PARAMETERS	10
INSTRUMENTATION	13
CAMERA CALIBRATION	15
DATA REDUCTION	15
SUMMARY	16

LIST OF ILLUSTRATIONS

Figure		Page
1.	Principle of Stereophotogrammetry	18
2.	Random Spot Pattern	19
3.	Scale and Vertical Reference Marks	20
4.	Experimental Instrumentation	21
5.	Geometrical Arrangement	22
6.	Instrumentation Schematic	23
7.	Sequence of Events	24
8.	Trolley - Top View	25
9.	Platform - Top View	26
10.	Platform - Bottom View	27
11.	Water Table Instrumentation System	28
12.	Calibration Pattern	29
13.	Lens Distortion	30
14.	Topography - Universal Plotter	31
15.	Topography - Analytical Solution	32

INTRODUCTION

The development of a photogrammetric method for the determination of the topography of liquid surfaces was undertaken at the request of the Harry Diamond Laboratories. Prior photogrammetric research at the BRL included both theoretical and experimental investigations with application to problems in projectile and missile trajectories, satellite orbits, as well as aerial triangulation and mapping.

The specific problem posed to the BRL occurred in connection with HDL investigations of the behavior of turbine gases in the subsonic and supersonic regions. For these studies a hydrodynamic analogue is provided from water table experiments to simulate the gas conditions. Thus, the topography of the liquid surface serves as an indicator for determining gas pressures and velocities necessary for the analysis of turbine performance. The BRL agreed to undertake the development of a measuring method which would provide the required data for the investigation of liquid surface behavior.

A stereophotogrammetric method was used to obtain an instantaneous and permanent record of the topography of the surface. This method was selected because only it would provide a three-dimensional model with sufficient detail for each set of experimental parameters.

MEASUREMENT METHOD

The measurement problem presents three interrelated factors:

(1) The scale of the photogrammetric model must be such that the depth of the water surface at any point may be determined to an accuracy of ± 25 microns.

(2) The stereo effect must be sufficient to permit accurate identification of details and depth resolution of the photographic image.

(3) The field of view must be large enough to include the entire area under investigation.

Conventional photogrammetric practice yields a mean error of ± 5 microns for typical coordinate measurements on photographic glass plates. Therefore, the required accuracy of the depth measurements indicates an object distance

of five times the image distance. A large base-height ratio, most easily obtained with a system of convergent cameras, provides a maximum stereo effect. However, the present problem requires the use of normal photography rather than convergent photography because of the small depth of field associated with a short object distance.

The stereophotogrammetric principle of normal (vertical) photography is shown in Figure 1, where

B = baseline between the two cameras

O_1 & O_2 = optical centers of cameras 1 & 2

f = focal length

P = object point

$p_x = x' - x''$

$\therefore \quad x'' = x' - p_x$

From Figure 1, the following formulas are derived for the coordinates (X, Y, Z):

$$X = \frac{B \cdot x'}{p_x} \qquad (1^a)$$

$$Y = \frac{B \cdot y'}{p_x} \qquad (1^b)$$

$$Z = \frac{B \cdot f}{p_x} \qquad (1^c)$$

Since p_x is very small it is of particular importance because it determines the accuracy of each coordinate.

Considering B and f as constants, we obtain the following expressions for the mean errors m_X, m_Y and m_Z:

$$m_X^2 = \left(\frac{dX}{dp_x}\right)^2 m_{p_x}^2 + \left(\frac{dX}{dx}\right)^2 m_{x'}^2 \qquad (2^a)$$

$$m_Y^2 = \left(\frac{dY}{dp_x}\right)^2 m_{p_x}^2 + \left(\frac{dY}{dy}\right)^2 m_{y'}^2 \qquad (2^b)$$

$$m_Z^2 = \left(\frac{dZ}{dp_x}\right)^2 m_{p_x}^2 \qquad (2^c)$$

Hence:

$$m_X^2 = \left(\frac{Bx'}{p_x^2}\right)^2 m_{p_x}^2 + \left(\frac{B}{p_x}\right)^2 m_{x'}^2 \qquad (3^a)$$

$$m_Y^2 = \left(\frac{By'}{p_x^2}\right)^2 m_{p_x}^2 + \left(\frac{B}{p_x}\right)^2 m_{y'}^2 \qquad (3^b)$$

$$m_Z^2 = \left(\frac{Bf}{p_x^2}\right)^2 m_{p_x}^2 \qquad (3^c)$$

Since:

$$\frac{B}{p_x} = \frac{X}{x'} = \frac{Y}{y'} = \frac{Z}{f} = M \quad \text{(scale factor)}$$

it follows that:

$$\frac{Bx'}{p_x^2} = \frac{XM}{B}$$

$$\frac{By'}{p_x^2} = \frac{YM}{B}$$

$$\frac{Bf}{p_x^2} = \frac{ZM}{B}$$

Hence:

$$m_X = XM\sqrt{\frac{m^2_{p_x}}{B^2} + \frac{m^2_{x'}}{X^2}} \qquad (4^a)$$

$$m_Y = XM\sqrt{\frac{m^2_{p_x}}{B^2} + \frac{m^2_{y'}}{Y^2}} \qquad (4^b)$$

$$m_Z = \frac{ZM}{B}\, m_{p_x} \qquad (4^c)$$

Equations (4^a) and (4^b) express the accuracy of X and Y as a function of the relative parallax accuracy and the accuracy of the measurements. Equation (4^c) shows that the relative distance accuracy is proportional to the relative parallax accuracy, and, since $M = \frac{Z}{f}$, that the distance error increases with the square of the distance for a given focal length.

The parallax can be measured more accurately in a stereo model than in two separate photographs, because of better identification and differentiation in depth.

PHOTOGRAMMETRIC PARAMETERS

Since the maximum amplitude of the waves in the experiments is ± 5mm a depth of field of 10mm is required. Values of depth of field for combinations of f/stop, object distance, and circle of confusion are shown in the following table.

TABLE I

DEPTH OF FIELD

(mm)

a (mm)	o (mm)	f - stop			
		5.6	8.0	11.0	16.0
400	0.02	2.6	3.8	5.2	7.6
	0.03	4.0	5.8	8.0	11.6
500	0.02	4.4	6.4	8.8	12.8
	0.03	6.8	9.6	13.2	19.2
600	0.02	6.8	9.6	13.2	19.2
	0.03	10.0	14.4	19.8	28.8

a = object distance

o = circle of confusion

Circles of confusion are selected to correspond approximately with the resolution of the photographic emulsion. For maximum light intensity, i.e., at f/5.6, a depth of field of 10mm is obtained with a 600mm object distance.

A ratio of 1:1.5 is an optimum base-height ratio for photogrammetric work using wide angle (90°) cameras in normal photography. However, a 1:1.5 ratio and 600mm object distance do not cover a sufficient area of the water surface. The required area is covered with a 600mm object distance and a baselength of 250mm which corresponds to a somewhat less favorable 1:2.4 base-height ratio.

The Scheimpflug condition is satisfied in normal photography where the object plane, the "mean plane" of the optical center, and the image plane intersect at infinity.

In any measuring problem, the accuracy of the final results depends on the precision of the raw data. In the present case, the water surface must be photographed from two positions in space and corresponding details must be identifiable and measurable with high precision.

Since in other water table experiments floating objects were used to define the surface of the water, an attempt was made to use small ceramic balls ranging in size from 0.05mm to 0.2mm in diameter. This method was not feasible because the balls clustered together in certain areas and left a void in other areas. Moreover, many balls submerged. A more satisfactory solution based on the reflectivity of the water surface was adopted. Laboratory experiments with milk demonstrated the desired characteristics. The requirement to approximate the consistency of water somewhat limited the selection of an emulsified solution. Various dyes and water soluble paints proved unsuccessful. The desired effect was produced by adding cutting oil as used in machine shops. The resulting blend retains sufficiently the properties of clear water and has adequate reflectivity.

A random spot pattern was projected on the water surface using a short duration flash tube (Fig. 2). A Balplex projector manufactured by Bausch and Lomb for photogrammetric work was selected because its short focal length lens provides a large depth of field and the lens can be oriented to establish the Scheimpflug condition. The standard projection lamp was replaced with a high energy flash tube. Thus, the short duration flash projection served as the camera shutter to effectively freeze the water surface during photography.

An adjustable metal ruler having graduations at the mean water level was photographed simultaneously with the experiment to provide the scale of the photogrammetric model. The ruler was located on the water table in such a way that the water surface was not affected. Similarly, other targets were photographed to establish a reference system for the elevations. The scale and vertical reference marks are shown in Figure 3.

Results of the parameter analysis were confirmed by laboratory experimentation prior to the design of the final instrumentation. The apparatus used for these tests is shown in Figure 4.

INSTRUMENTATION

The major components of the instrumentation system are two 100mm focal length, f/5.6 lenses and a projector. The geometrical arrangement of the major components was established by the photogrammetric parameters and is shown in Figure 5.

A schematic of the recording system and the water table is shown in Figure 6. A trolley is used to transport the system along the water table. Operational procedures are facilitated by having the instrumentation in place only when photographic recordings are required. The trolley serves as a base for the platform and contains the electrical control components.

The trolley, which is 27.5 inches long, 26.9 inches wide and 11.9 inches high, is a weldment fabricated with 1/4 inch 6061-T6 aluminum plate and liberally reinforced with gussets. Two end panels expose the electrical components for servicing and a side panel provides access to the projector for adjustments and servicing. An electrical control panel is located on the operator's side of the trolley.

The trolley has four nylon wheels which roll on two parallel rails located along the top edge of the water table. Three jacks attached to the trolley are applied to the rails of the water table to provide a firm support during photography. The jacks have five positions. In one position the nylon wheels support the trolley. The other four positions correspond to the mean depth of the water. Four carrying handles are attached to two sides of the trolley.

A rigid platform holds the major components so that their relative positions and orientations will be stable throughout a series of experiments. It is constructed from 1/4 inch 6061-T6 aluminum plate, and is 26-1/4 inches long, 23 inches wide and 2-3/8 inches high. The two cameras and the projector are fixed to the platform so that their object planes are coincident within mechanical tolerances (Fig. 5). An all way level related to the object plane is mounted in the platform and is used to orient the cameras to the mean water

level. A gauge of calibrated length is attached to the platform with a ball socket near one of the three leveling screws. By means of the leveling screw this portion of the platform is located at the proper height above the mean water level. When the end of the gauge contacts the water surface, the cameras and projector are located at the required distance above the water surface for photography at the 600mm object distance. The remaining two screws are used to level the platform.

The cameras use Aviogon 100mm f/5.6 lenses. The lens cone body is a standard component of the Wild RC-7 Automatic Plate Camera. Each body is modified for photography at 600mm object distance by inserting a 20mm spacer under the focal plane frame. Four fiducial projectors and a frame counter are incorporated in the camera body. Each camera has a shutter consisting of two rotating discs. The shutters are modified from their standard trip mode of operation to a direct drive. A motor drives a gear train which mechanically couples the two shutters. The projector's flashtube, which is gated by the mechanical shutter, performs the function of a shutter in making an exposure.

Records are obtained on glass plates 15.5 cm X 16.8 cm X 5mm thick. Each plate is loaded in a sheet metal magazine having a dark slide. The individual magazines are manually inserted into a plate adapter. After the dark slide is retracted, a lever on the plate adapter applies a uniformly distributed pressure to press the plate against the focal plane frame.

A random spot pattern is projected onto the water surface by a modified Balplex Projector in which the standard 28 VDC lamp and socket are replaced by a flash tube and an adjustable holder. An Edgerton, Germeshausen & Grier FX-29 flashtube performs in either of two modes of operation; a repetitive flash for focusing the projector and a single flash to "freeze" the water surface for photography. The energy of the single flash is 265 watt-seconds and the flash duration is a nominal 300 microseconds.

The electrical controls are located in the trolley. A sequence of events initiated by a manually operated push button switch at t_o is shown in Figure 7.

Various details of the instrumentation are shown in Figures 8 to 11.

CAMERA CALIBRATION

The cameras were calibrated after they were modified for photography at 600mm object distance. A pattern was drawn on aluminum inserted paper (Fig. 12). The graduations were measured with an accuracy of ± 25 microns, using a 500mm glass scale with subdivisions of 100 microns. The calibration pattern was photographed by each camera separately and the photographs were measured monocularly on the stereocomparator. The comparator measurements were then reduced by means of available computer programs to determine the distortion of each camera. The plotted results show that the two cameras have very nearly the same distortion characteristics (Fig. 13).

DATA REDUCTION

Basically there are two reduction methods available. First, the data reduction can be performed on a universal plotter, e.g., a Wild A-7 Autograph. In essence, such an instrument is a three dimensional triangulator, based on the principle of simulation. The topography of a water surface will be expressed directly by a set of isometric curves, in analogy to the evaluation of conventional aerial photography for the purpose of compiling topographic maps. Experience will show whether this method will become the more economical for the reduction of data from water table experiments.

Presently, preference is given to the more accurate reduction method, i.e., the method based on the analytical determination of a sufficient number of points which can be measured on the stereo model. Mathematical expressions give the XYZ coordinates of any one observed point. These points, in turn, are used to construct the individual isometric curves by a process of interpolation.

The coordinates are obtained by measuring the model on a stereocomparator. After correction for instrumental errors the normalized coordinates serve as input for a computer program, by which the spatial coordinates are computed. The XY coordinates define the locations of the points while the Z coordinates represent the corresponding heights.

Evaluations with both the universal plotter and the analytical method have shown general agreement between the results. In these tests the plate measurements were performed with a precision of ± 5 microns. The propagation

of this error is determined by the scale of 1:5 and the base-height ratio of 1:2.4. Hence, the accuracy of measuring the water table surface amounts to about ± 25 microns in position and ± 60 microns in elevation. These values pertain to the field as a whole and it is estimated that for small areas near the center the accuracy will be considerably higher, i.e. of the order of ± 30 microns in elevation.

Moreover, it is felt that considerable improvement, by as much as a factor of 2, can be achieved by creating a sharper image of the projected point pattern.

The use of a universal plotter in production work yields elevation data with an accuracy of about 1:5000 of the object distance, i.e., ± 120 micron in the present application.

Figures 14 and 15 represent results obtained by universal plotter and analytical treatment, respectively.

SUMMARY

A water table, serving as a hydrodynamic analogue, is being used by HDL to study the behavior of turbine gases.

A stereophotogrammetric method, commonly associated with aerial triangulation and mapping problems, has been developed to determine the topography of the surface. The instrumentation system consists of two cameras, having 100mm f/5.6 lenses, and a projector. The cameras photograph simultaneously a pattern of random spots projected by a flash source onto the reflecting water surface.

The topography is determined by two methods. The first is an analogue method using a universal plotter which simulates the geometry of the photogrammetric system. The second method is an analytical method whereby the coordinates of individual points in the topography are calculated.

The analogue solution is the more economical, whereas the analytical solution is the more accurate.

The accuracy of the elevation measurements by the analogue method amounts to about ± 120 microns.

The accuracy of the analytical method amounts to ±60 microns overall and ±30 microns for small areas near the center. An increase in accuracy by a factor of 2 is believed to be possible by improving the sharpness of the projected spots.

Heinz Poetzschke

HEINZ G. POETZSCHKE

Donald F. Menne

DONALD F. MENNE

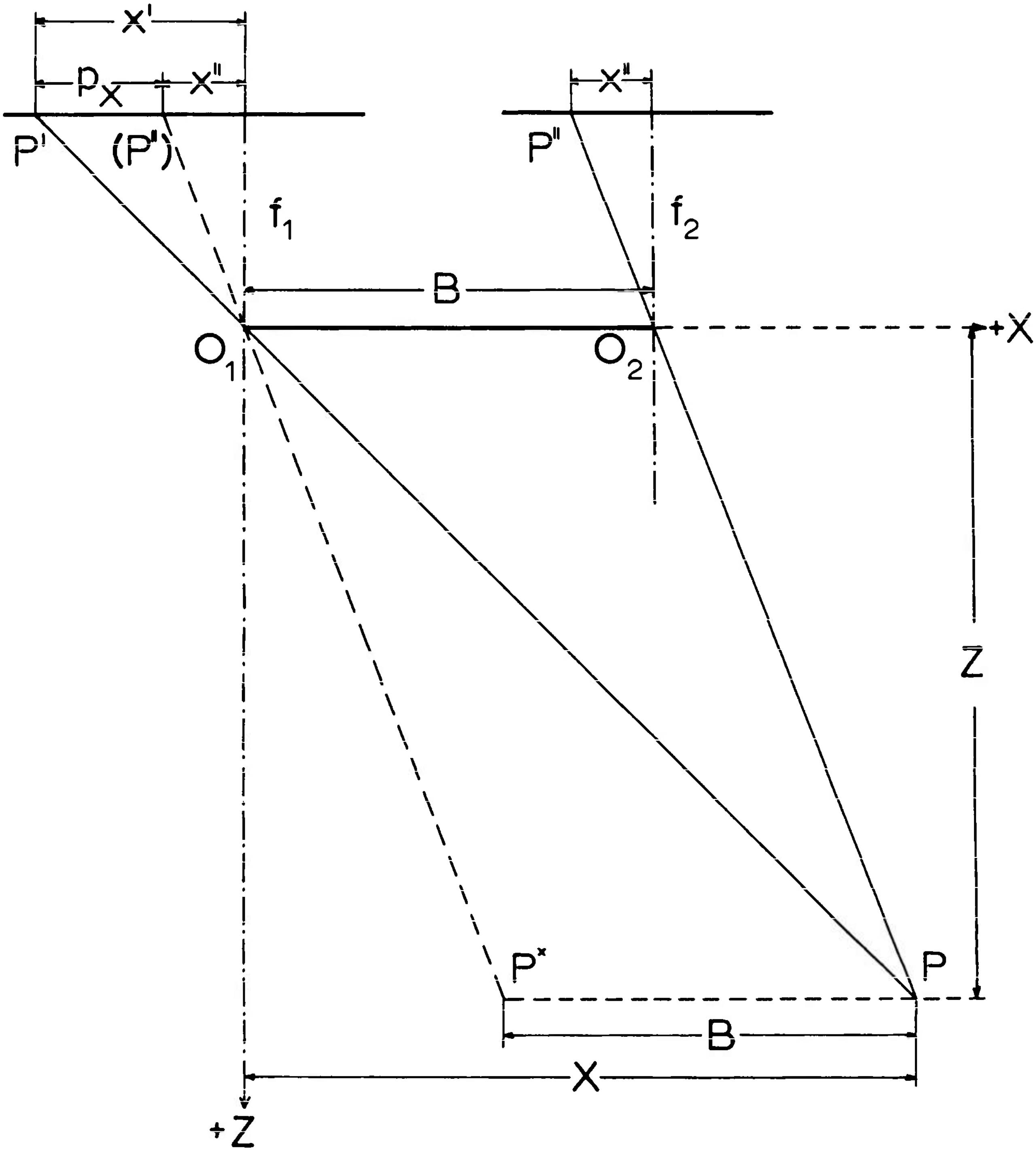

Figure 1. Principle of Stereophotogrammetry

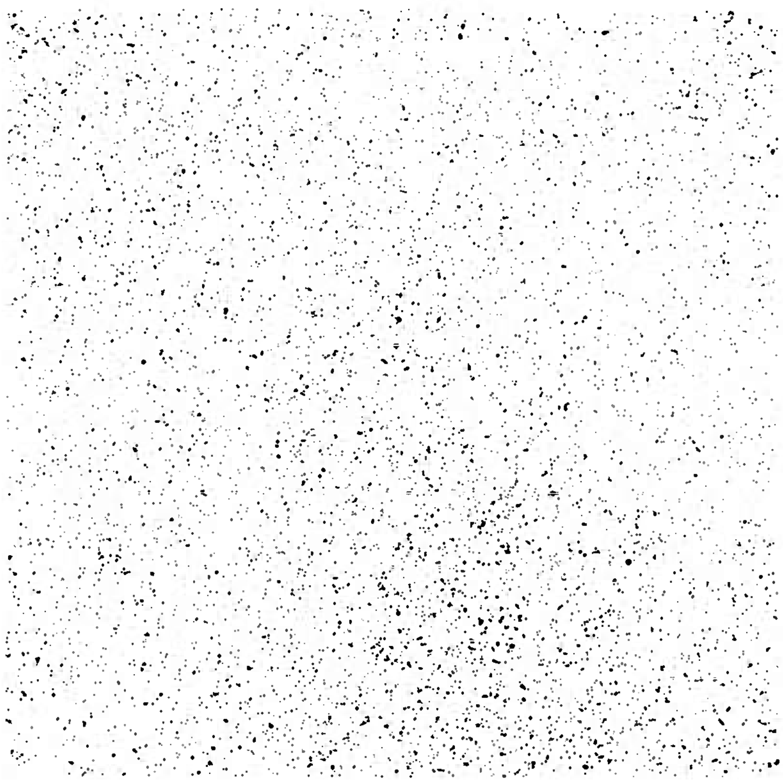

Figure 2. Random Spot Pattern

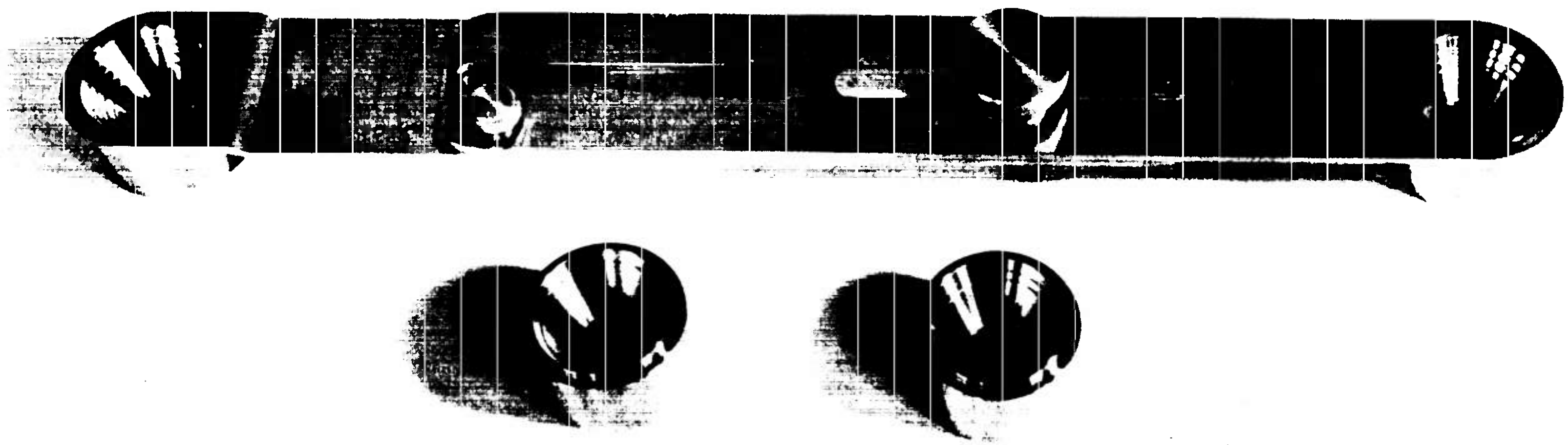

Figure 3. Scale and Vertical Reference Marks

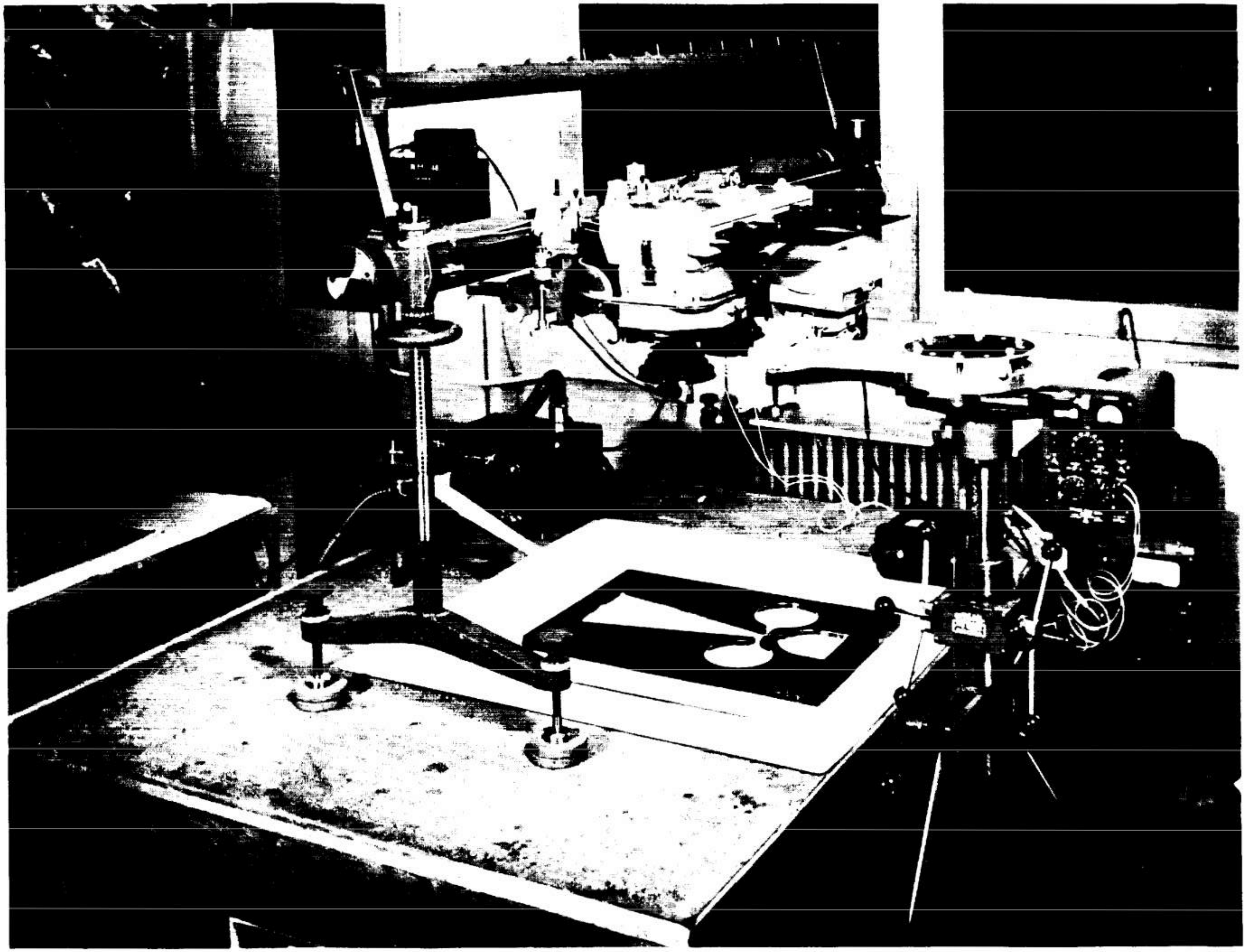

Figure 4. Experimental Instrumentation

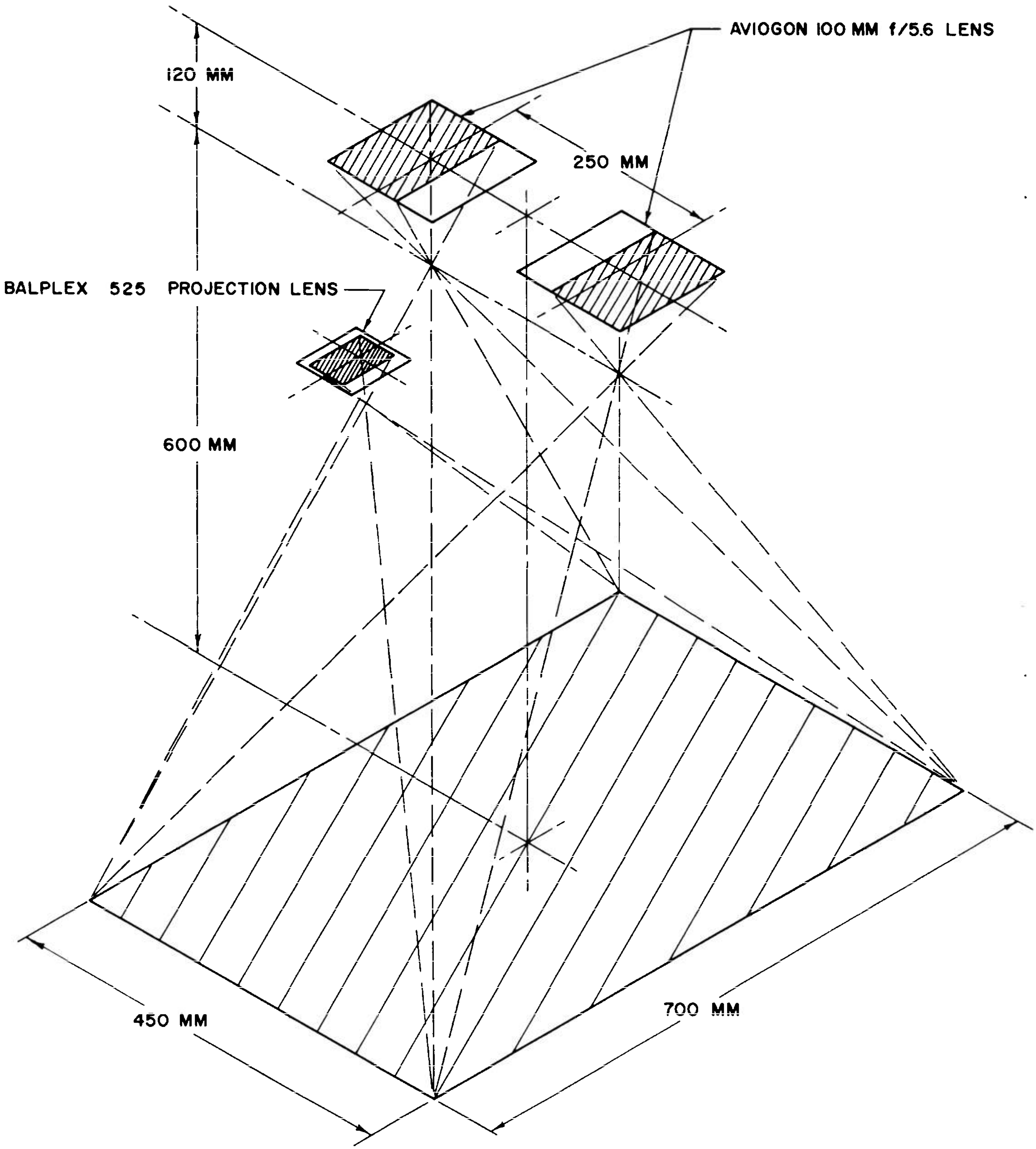

Figure 5. Geometrical Arrangement

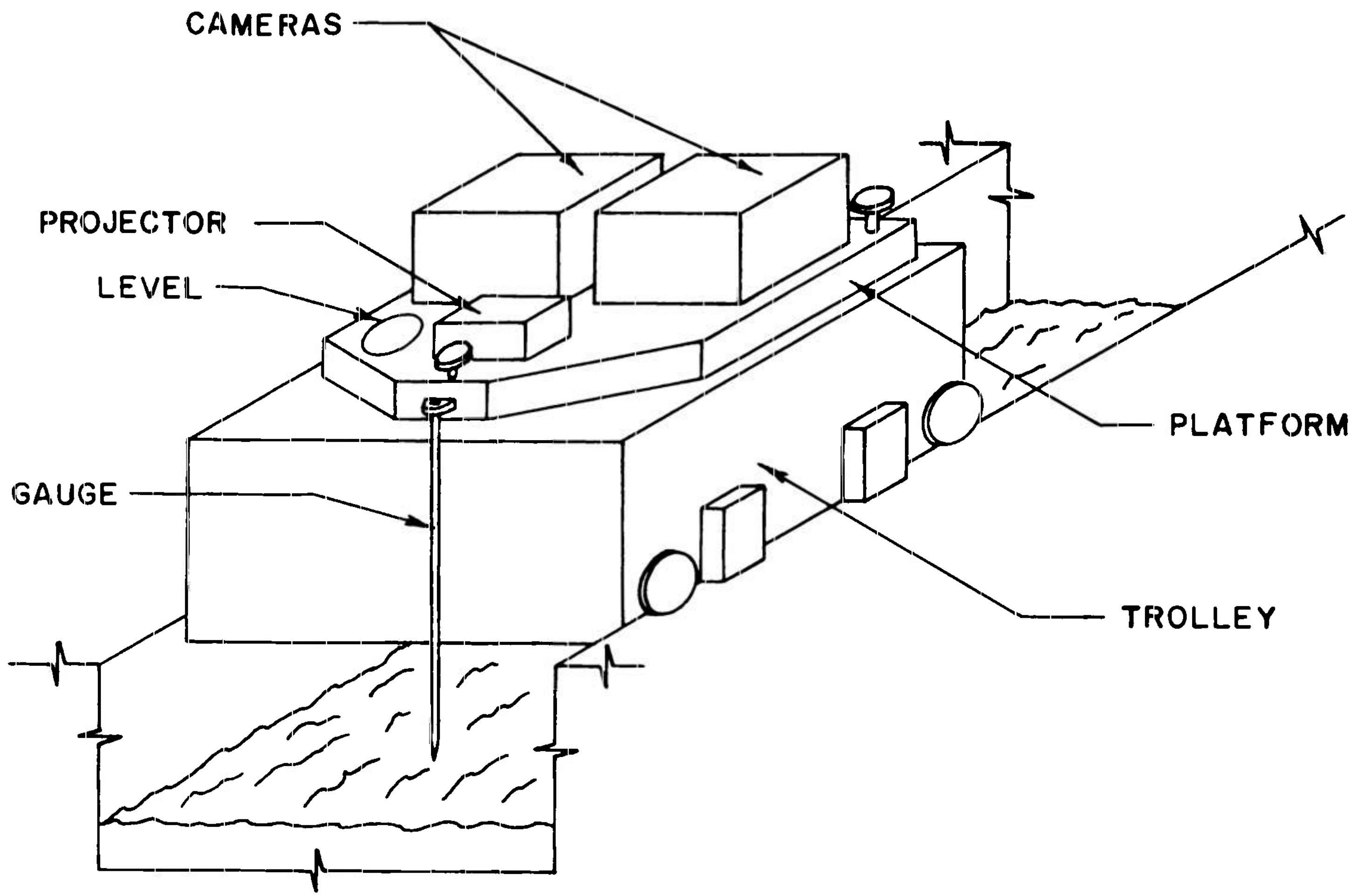

Figure 6. Instrumentation Schematic

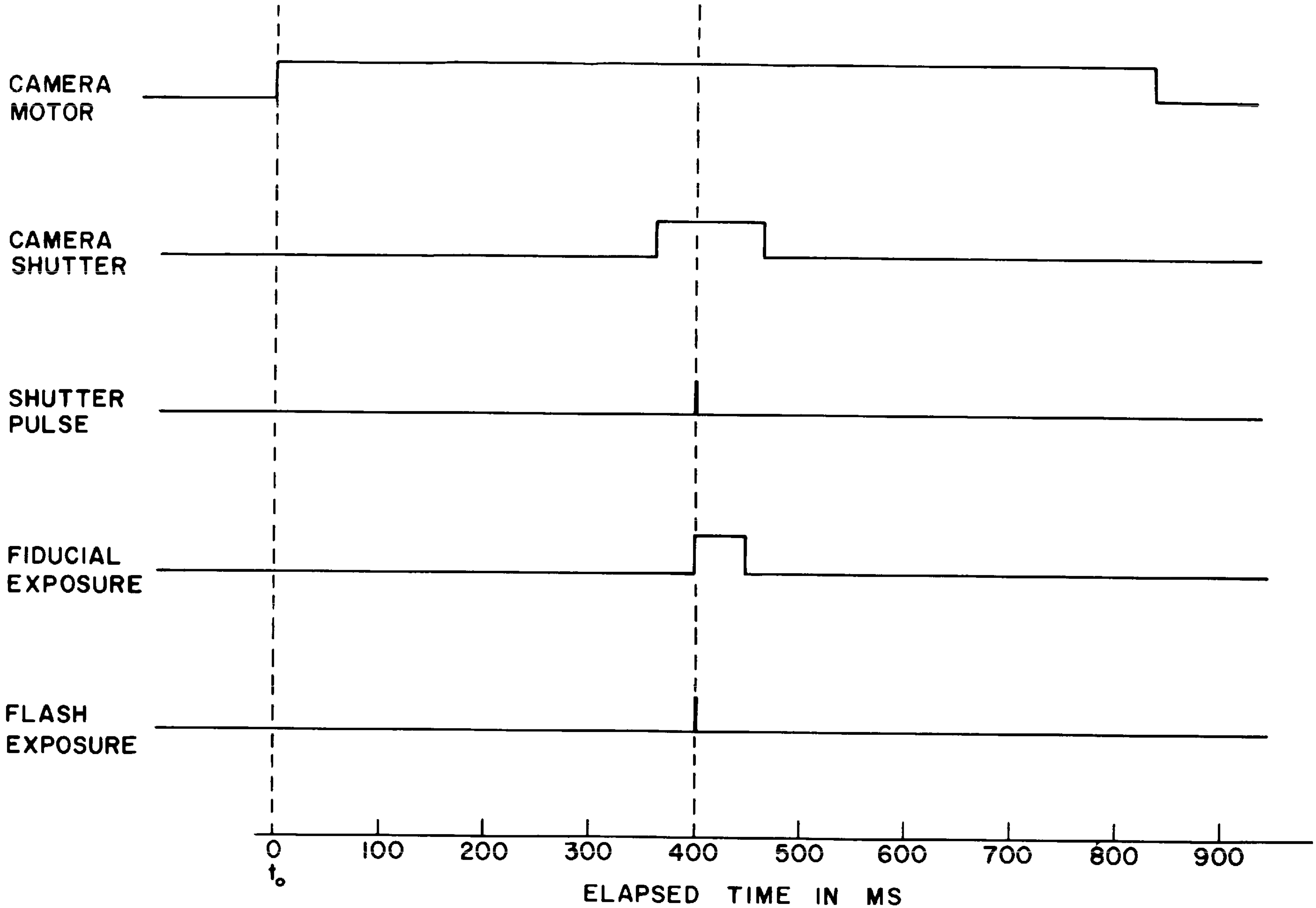

Figure 7. Sequence of Events

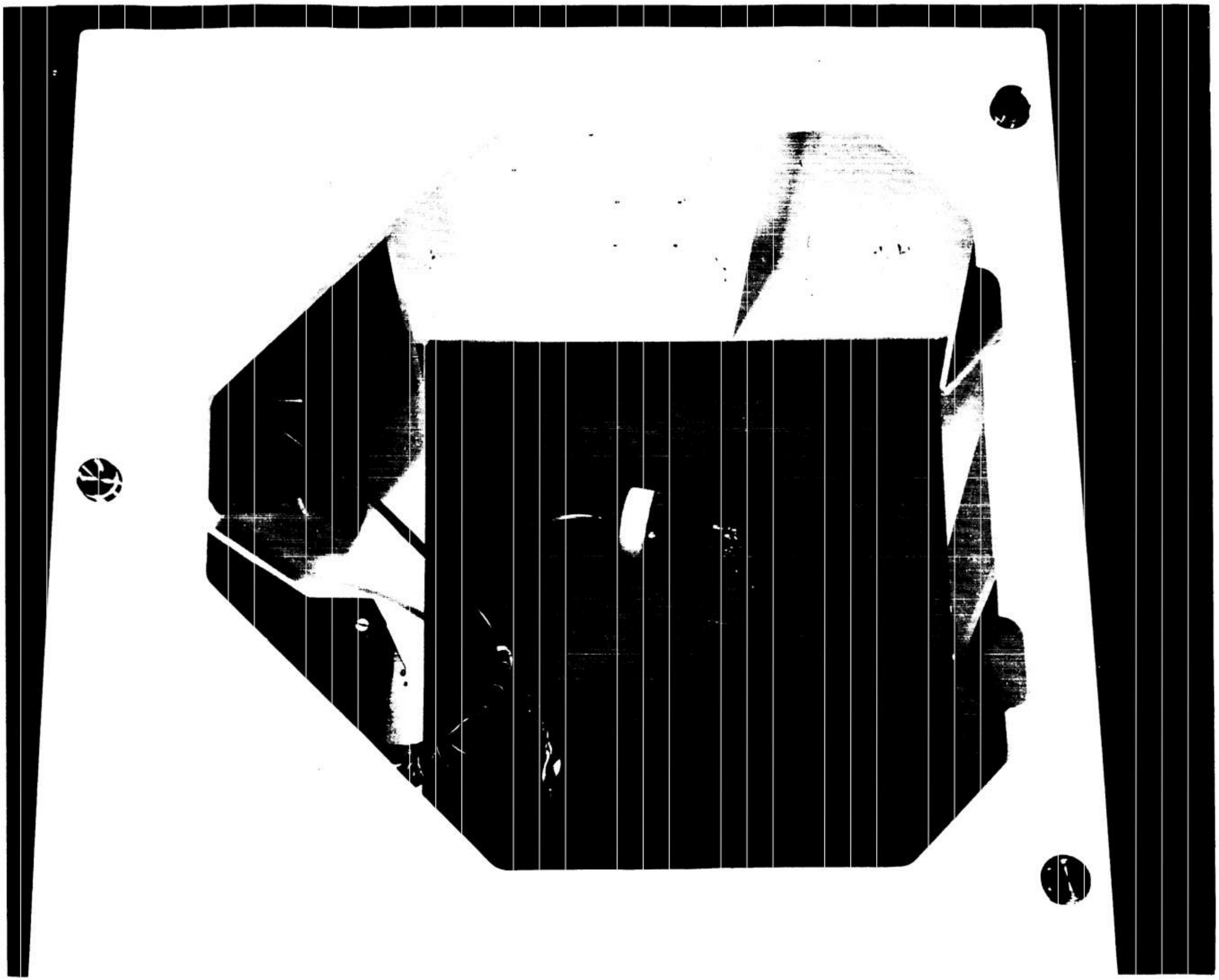

Figure 8. Trolley - Top View

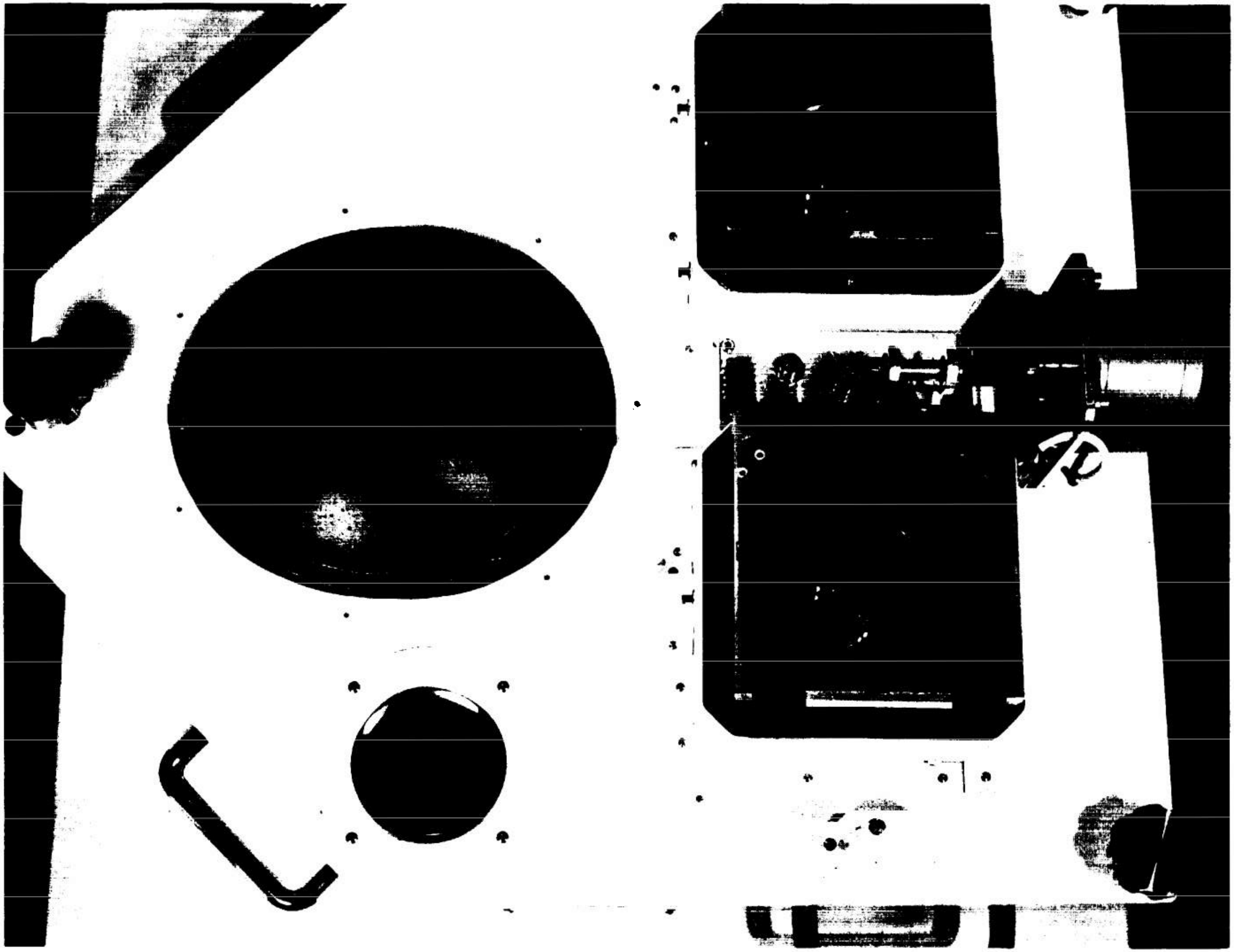

Figure 9. Platform - Top View

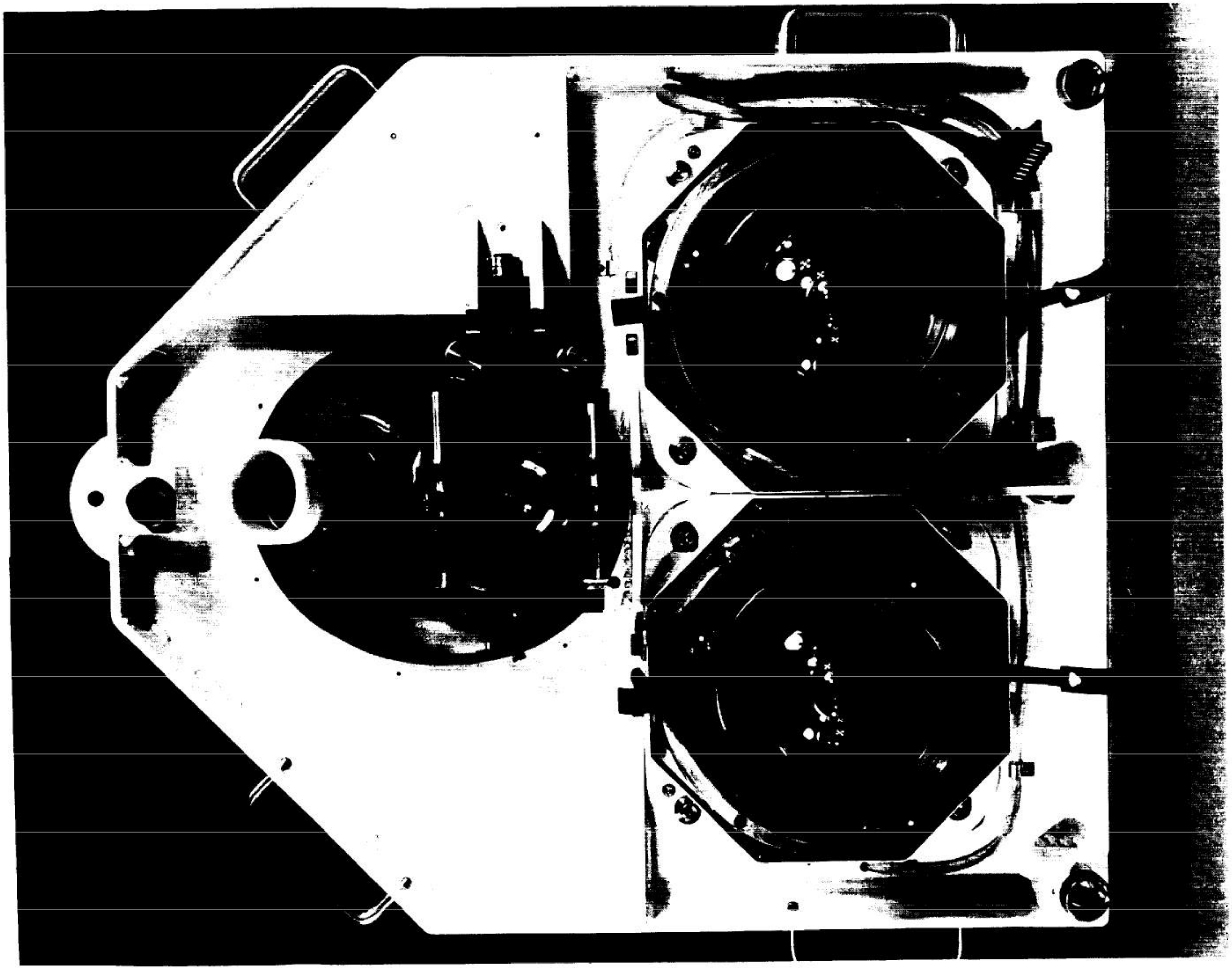

Figure 10. Platform - Bottom View

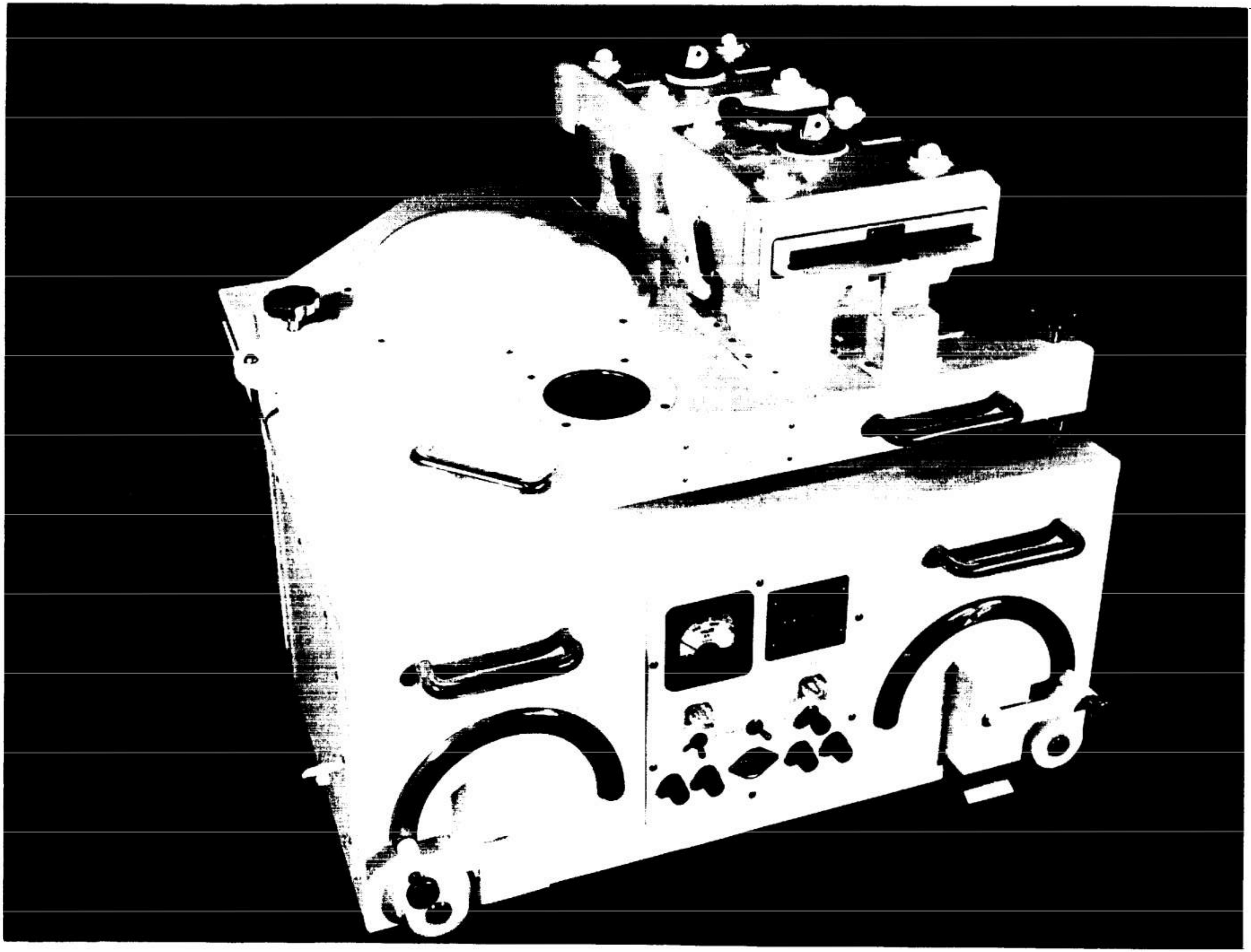

Figure 11. Water Table Instrumentation System

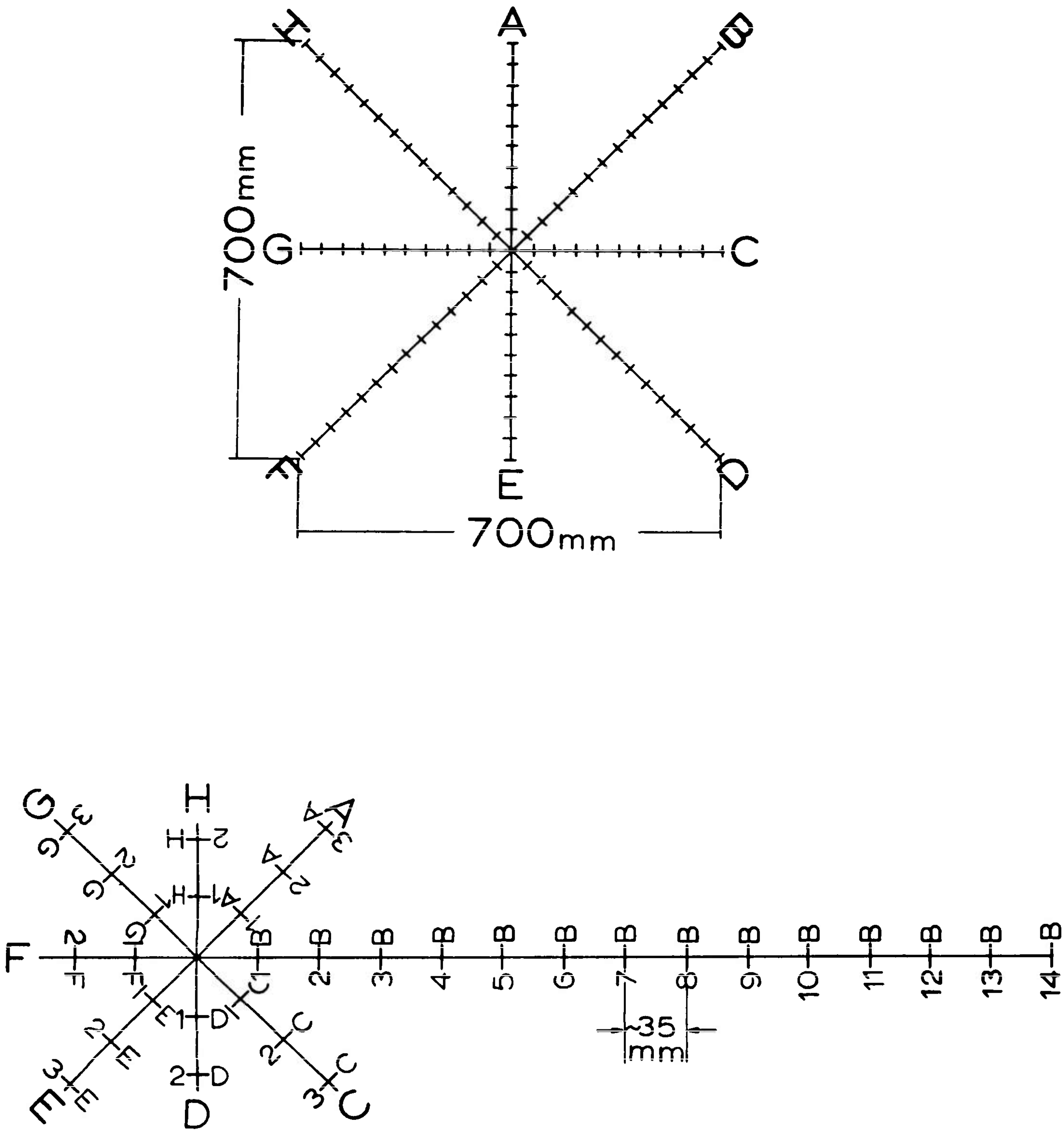

Figure 12. Calibration Pattern

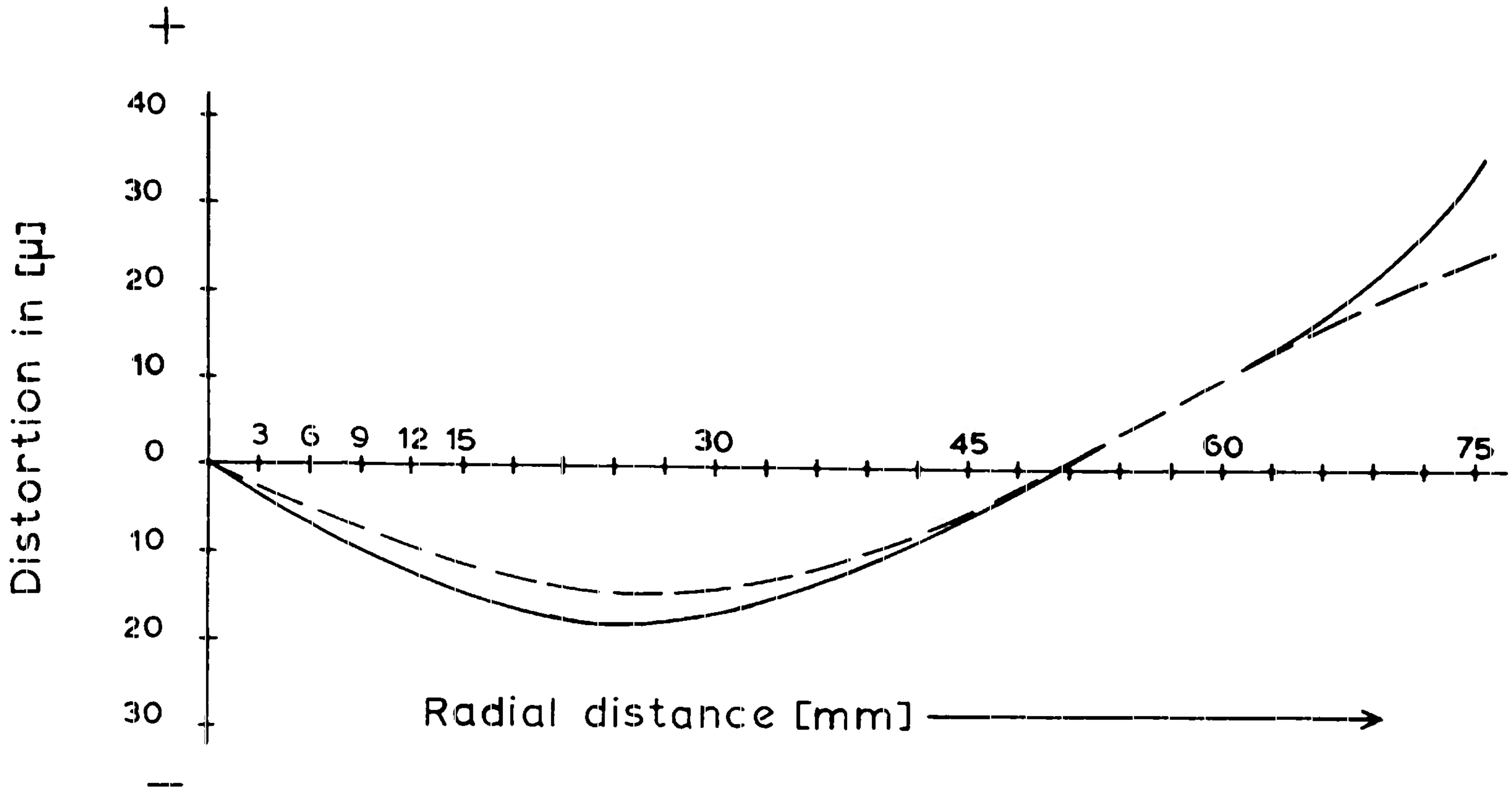

Figure 13. Lens Distortion

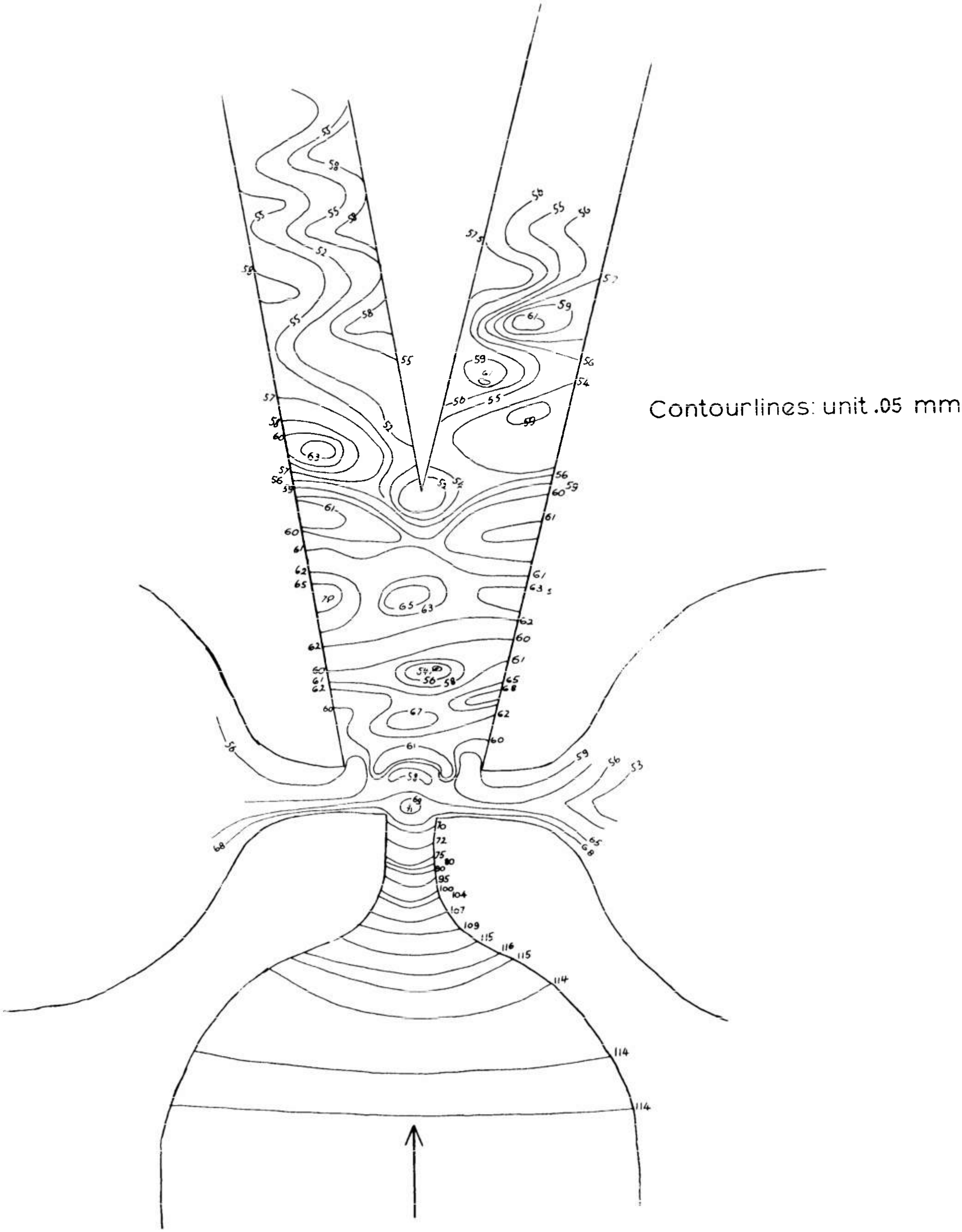

Figure 14. Topography - Universal Plotter

Contourlines: unit 0.1 mm

Figure 15. Topography - Analytical Solution

No. of Copies	Organization
10	Director Armed Services Technical Information Agency ATTN: TIPCR Arlington Hall Station Arlington 12, Virginia
1	Joint Coordinating Committee on Guided Missiles Office of the Assistant Secretary of Defense (R&D) The Pentagon Washington 25, D. C.
1	Commanding General U. S. Army Materiel Command ATTN: AMCRD-RS-PE-Bal Research and Development Directorate Washington 25, D. C.
1	Commanding Officer Harry Diamond Laboratories ATTN: Technical Information Office, Branch 012 Washington 25, D. C.
2	Commanding Officer Harry Diamond Laboratories ATTN: Mr. Francis E. Washer Mr. Raymond Warren Washington 25, D. C.
2	Commanding Officer Army Research Office (Durham) ATTN: CRD-AA-IPL Dr. Theodore W. Schmidt Box CM, Duke Station Durham, North Carolina
1	Redstone Scientific Information Center ATTN: Chief, Document Section U. S. Army Missile Command Redstone Arsenal, Alabama
3	Commanding General U. S. Army Missile Command ATTN: Dr. Ernst Stuhlinger Dr. Hellmut Holzer Dr. Bruns Redstone Arsenal, Alabama
1	Commanding General U. S. Army Signal Corps Engineering Labs. ATTN: Tech Document Center Fort Monmouth, New Jersey
3	Commanding General White Sands Missile Range ATTN: ORDBS-TS-TIB Mr. Ted Durrenberger New Mexico
3	Chief, Bureau of Naval Weapons ATTN: DIS-33 Department of the Navy Washington 25, D. C.
2	Commander Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland
1	Commander U. S. Naval Ordnance Test Station China Lake, California
2	Commander Naval Proving Ground ATTN: Dr. W. A. Kemper Dr. C. J. Cohen Dahlgren, Virginia
1	Commander U. S. Naval Photographic Interpretation Center Anacostia Station Washington 20, D. C.

DISTRIBUTION LIST

No. of Copies	Organization
1	Commander U. S. Naval Hydrographic Center Washington 25, D. C.
2	Commander U. S. Naval Air Missile Test Center Point Mugu, California
2	Director U. S. Naval Observatory ATTN: Dr. William Markowitz Dr. C. M. Clemence Washington 25, D. C.
1	Director Air University Library Maxwell Air Force Base Alabama
3	APGC (PGTRI, PGEES, Mr. W. A. Brown) Eglin Air Force Base Florida
2	AFMTC ATTN: (AFMT Tech Lib. MU-135) Patrick Air Force Base Florida
2	AFCRL (Geophysics Research Directorate) L. G. Hanscom Field Bedford, Massachusetts
1	ARL Wright-Patterson Air Force Base Ohio
1	RADC Griffiss Air Force Base Rome, New York
1	Commanding Officer Air Force Aeronautical Chart Service ATTN: Division of Photogrammetry Washington, D. C.
1	HADC (SEB, FDL) Holloman Air Force Base New Mexico
1	APCS ATTN: Capt. Charles J. Finley Orlando Air Force Base Florida
1	ACIC ATTN: Chief Photogrammetry Research Branch Mr. Edwin Roth Air, Photographic and Charting Service (MATS) Second & Arsenal Streets St. Louis 18, Missouri
1	Director National Science Foundation ATTN: Technical Library Washington, D. C.
3	Director U. S. Geological Survey ATTN: Chief, Topographic Eng. Mr. Russel K. Bean Mr. R. E. Altenhofen Washington 25, D. C.

DISTRIBUTION LIST

No. of Copies	Organization
7	Commanding Officer U. S. Army Map Service ATTN: Photogrammetric Division Col. Robert C. Miller Mr. A. Nowicki Mr. J. Theis Mr. C. Born Mr. James P. Webb, Chief CSI Div. Mr. S. W. Henriksen, Dept. of Geodesy Corps of Engineers 6500 Brooks Lane Washington 16, D. C.
1	NASA Goddard Space Flight Development Center ATTN: Dr. Nordberg Satellite Application Division 4555 Overlook Avenue, S. W. Washington 25, D. C.
1	Director National Aeronautics & Space Agency ATTN: Mr. Richard M. Dickerson Langley Research Center Langley Field, Virginia
1	Director National Bureau of Standards ATTN: Dr. Irvine C. Gardner Washington 25, D. C.
9	Director U. S. Coast & Geodetic Survey ATTN: Capt. L. W. Swanson Mr. G. C. Tewinkel Mr. Charles Whitten Mr. L. G. Simmons Capt. F. R. Gossett Mr. Wm. D. Harris LCDR E. A. Taylor CDR Woodcock Mr. Erwin Schmid Washington 25, D. C.

No. of Copies	Organization
1	U. S. Geological Survey ATTN: Mr. Morris M. Thompson 1109 N. Highland Street Arlington, Virginia
1	U. S. Dept. of the Interior ATTN: Henry P. Cate, Jr. Chief, Branch of Computation Bureau of Land Management Division of Engineering 555 Cordova Street Anchorage, Alaska
5	Director Geodesy, Intelligence & Mapping R&D Agency ATTN: Mr. William C. Cude (Dir.) Mr. D. Esten Mr. John T. Pennington Mr. Matos Dr. H. H. Schmid Fort Belvoir, Virginia
4	Goddard Space Flight Center NASA ATTN: Mr. W. M. Kaula, Theoretical Division Mr. William B. Taylor Dr. Norberg Dr. John O'Keefe Greenbelt, Maryland
1	Aeroflex Laboratories Incorporated ATTN: C. L. Benesh, Eng. Sales Mgr. 48-25 36th Street Long Island City 1, New York
1	Applied Physics Laboratory ATTN: Dr. W. H. Guier The Johns Hopkins University Howard County, Maryland

DISTRIBUTION LIST

No. of Copies	Organization
1	Director Astrophysical Observatory ATTN: Dr. Fred Whipple 60 Garden Street Cambridge 38, Massachusetts
2	Autometric Corporation Paramount Building ATTN: Dr. Ulrich Heidelauf Mr. E. L. Merritt New York 36, New York
1	Bausch & Lomb Optical Co. ATTN: Mr. Heinz Gruner 262 St. Paul Street Rochester, New York
1	Bausch & Lomb Incorporated ATTN: Mr. Rex R. McHail, Dept. G-53 62663 Lamb Park Rochester 2, New York
1	Brookhaven National Laboratory ATTN: O. B. Reading Upton, New York
1	Bendix Aviation Corporation ATTN: V. A. van Praag Computer Division 5630 Arbor Vitae Street Los Angeles 45, California
1	Cincinnati Observatory ATTN: Dr. Paul Herget Cincinnati, Ohio
1	Instrument Corporation of Florida ATTN: Mr. D. C. Brown Box 1226 Melbourne, Florida
1	Institute of Geophysics and Planetary Physics ATTN: Dr. G. J. F. MacDonald Los Angeles Laboratories University of California Los Angeles 24, California
1	International Business Machine Corporation ATTN: Mr. John V. Sharp Endicott, New York
2	Lockwood Kessler & Bartlett, Inc. ATTN: Mr. Harold Johnson Mr. Ford Bartlett 1 Aerial Way Syosset, New York
1	Photogrammetry, Inc. ATTN: Mr. Gomer T. McNeil Silver Spring, Maryland
1	RCA Service Co., Incorporated ATTN: RCA Data Reduction Gr. Analysis Unit Mr. Duane Brown Patrick Air Force Base, Florida
1	Ramo - Wooldridge Corporation ATTN: Dr. E. Stern 5730 Arbor Vitae Street P. O. Box 45067 Airport Station Los Angeles 45, California
1	Palmer Physical Laboratory ATTN: Dr. R. H. Dicke Princeton University Princeton, New Jersey
1	Technical Operations, Inc. ATTN: Mr. Samuel S. Holland Burlington, Massachusetts

DISTRIBUTION LIST

No. of Copies	Organization
1	Telecomputing Corporation Engineering Services Division Burbank, California
1	Transmares Corporation 15 William Street New York 5, New York
1	Western Development Labs. Philco Corporation ATTN: Mr. Eric Besag 3875 Fabian Way Palo Alto, California
3	Wild Heerbrugg Instruments, Inc. ATTN: Mr. K. E. Reynolds Main & Covert Streets Port Washington, New York
5	Zeiss - Aerotopograph ATTN: Mr. Marshall S. Wright 929 Highgate Road Alexandria, Virginia
2	Kern Instruments, Inc. ATTN: Mr. F. E. Davatz 120 Grand Street White Plains, New York
1	Director Physical Research Lab. Boston University Boston, Massachusetts
1	Cornell University ATTN: Prof. Arthur J. McNair Center of Aerial Photographic Studies School of Civil Engineering Ithaca, New York
1	Franklin Institute ATTN: Mr. Charles Moench 20th St. & Benjamin Franklin Parkway Philadelphia, Pennsylvania
1	Massachusetts Institute of Technology ATTN: C. L. Miller Dept. of Civil & Sanitary Eng. Director Photogrammetry Lab. Cambridge 39, Massachusetts
1	New Mexico School of Agriculture and Mechanic Arts ATTN: Dr. George Gardiner State College, New Mexico
1	National Academy of Science ATTN: Dr. Pembroke J. Hart, Jr. Washington 25, D. C.
3	Ohio State University ATTN: Prof. Dr. Brandenberger Prof. A. R. Robbins Prof. Heiskanen Mapping & Charting Research Lab. Columbus, Ohio
1	Princeton University ATTN: Prof. Sumner B. Irish Department of Civil Engineering Princeton, New Jersey
3	Smithsonian Institute Astrophysical Observatory ATTN: Dr. F. L. Whipple Mr. Imre G. Isaacs Dr. Y. Kozai 60 Garden Street Cambridge 38, Massachusetts

DISTRIBUTION LIST

No. of Copies	Organization
2	Syracuse University L. C. Smith College of Engineering ATTN: Prof. Arthur Faulds Prof. Paul G. Brennan Department of Civil Engineering Syracuse 10, New York
1	Syracuse University ATTN: Photogrammetric Department Department of Civil Engineering Syracuse, New York
2	Smithsonian Institute ATTN: Dr. Karl G. Henize Dr. J. Allen Hynek Washington 25, D. C.
2	University of Illinois ATTN: Dr. H. M. Karara Prof. Milton O. Schmid Department of Civil Engineering Urbana, Illinois
1	University of Michigan ATTN: Prof. Edward Young Ann Arbor, Michigan
1	University of New York ATTN: Dr. W. M. Ewing Lamount Geological Laboratory New York, New York
2	University of Maryland ATTN: Mr. Gross Mr. Bowers College Park, Maryland
1	University of Pennsylvania Computing Lab. ATTN: Mr. John B. Crozier Philadelphia, Pennsylvania

No. of Copies	Organization
1	Mr. Robert Zurlinden 2118 - 37th Street, N. W. Washington 7, D. C.
1	Yale University Observatory ATTN: Dr. Dirk Brouwer New Haven 11, Connecticut
1	V. Zay Smith, Associated Consulting Geologists ATTN: John McMurchy 1143 - 17th Avenue, S. W. Calgary, Alberta
10	The Scientific Information Officer Defence Research Staff British Embassy 3100 Massachusetts Avenue, N. W. Washington 8, D. C. Of Interest to: Prof. E. H. Thompson University College London, W. C. 1 England
4	Defence Research Member Canadian Joint Staff 2450 Massachusetts Avenue, N. W. Washington 8, D. C. Of Interest to: National Research Council of Canada ATTN: Mr. T. J. Blachut Mr. G. H. Schut Ottawa 2, Ontario

AD ______________ Accession No. ______________ UNCLASSIFIED

Ballistic Research Laboratories, APG
A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES
H. G. Poetzschke and D. F. Menne

Photogrammetry - Signal surfaces
Topographic cameras - Design

BRL Report No. 1196 March 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

A stereophotogrammetric method has been developed for the determination of the topography of liquid surfaces, which serve as an analogue for gas pressures and velocities in the evaluation of turbine performance.

An instrumentation system has been constructed, consisting of two modified Wild RC-7 cameras with microflash projection of a random pattern of spots to identify the water table surface.

The reduction of the data was accomplished by both analogue and analytical methods. The analogue method, including automatic plotting, was the more economical and yielded an accuracy of $\pm$120 microns. The analytical method, involving manual plotting, resulted in an overall accuracy of $\pm$60 microns, and an accuracy of $\pm$30 microns for small areas near the center.

AD ______________ Accession No. ______________ UNCLASSIFIED

Ballistic Research Laboratories, APG
A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES
H. G. Poetzschke and D. F. Menne

Photogrammetry - Signal surfaces
Topographic cameras - Design

BRL Report No. 1196 March 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

A stereophotogrammetric method has been developed for the determination of the topography of liquid surfaces, which serve as an analogue for gas pressures and velocities in the evaluation of turbine performance.

An instrumentation system has been constructed, consisting of two modified Wild RC-7 cameras with microflash projection of a random pattern of spots to identify the water table surface.

The reduction of the data was accomplished by both analogue and analytical methods. The analogue method, including automatic plotting, was the more economical and yielded an accuracy of $\pm$120 microns. The analytical method, involving manual plotting, resulted in an overall accuracy of $\pm$60 microns, and an accuracy of $\pm$30 microns for small areas near the center.

AD ______________ Accession No. ______________ UNCLASSIFIED

Ballistic Research Laboratories, APG
A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES
H. G. Poetzschke and D. F. Menne

Photogrammetry - Signal surfaces
Topographic cameras - Design

BRL Report No. 1196 March 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

A stereophotogrammetric method has been developed for the determination of the topography of liquid surfaces, which serve as an analogue for gas pressures and velocities in the evaluation of turbine performance.

An instrumentation system has been constructed, consisting of two modified Wild RC-7 cameras with microflash projection of a random pattern of spots to identify the water table surface.

The reduction of the data was accomplished by both analogue and analytical methods. The analogue method, including automatic plotting, was the more economical and yielded an accuracy of $\pm$120 microns. The analytical method, involving manual plotting, resulted in an overall accuracy of $\pm$60 microns, and an accuracy of $\pm$30 microns for small areas near the center.

AD ______________ Accession No. ______________ UNCLASSIFIED

Ballistic Research Laboratories, APG
A PHOTOGRAMMETRIC METHOD FOR DETERMINING THE TOPOGRAPHY OF LIQUID SURFACES
H. G. Poetzschke and D. F. Menne

Photogrammetry - Signal surfaces
Topographic cameras - Design

BRL Report No. 1196 March 1963

RDT & E Project No. 1M222901A215
UNCLASSIFIED Report

A stereophotogrammetric method has been developed for the determination of the topography of liquid surfaces, which serve as an analogue for gas pressures and velocities in the evaluation of turbine performance.

An instrumentation system has been constructed, consisting of two modified Wild RC-7 cameras with microflash projection of a random pattern of spots to identify the water table surface.

The reduction of the data was accomplished by both analogue and analytical methods. The analogue method, including automatic plotting, was the more economical and yielded an accuracy of $\pm$120 microns. The analytical method, involving manual plotting, resulted in an overall accuracy of $\pm$60 microns, and an accuracy of $\pm$30 microns for small areas near the center.